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ABSTRACT

In many countries significant amounts of public funding are devoted to supporting firms' R&D and innovation projects. Here, using panel data on the innovation activities of Irish manufacturing firms we examine the legacy effects of public subsidies for new product development and R&D. We examine five alternative mechanisms through which such effects may occur: input additionality, output additionality, and congenital, inter-organisational and experiential behavioural additionality. Tests suggest contrasting legacy effects with R&D subsidies generating legacy output additionality effects while new product development subsidies have legacy congenital and inter-organisational behavioural additionality effects. Our results have implications for innovation policy design and evaluation.

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Keywords: innovation policy, additionality, evaluation, Ireland

JEL Codes: O32, L1, O38; Q34; L26

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1. INTRODUCTION

In many countries significant amounts of public funding are devoted to supporting private firms' R&D and innovation projects through subsidies or grants (Meuleman and De Maeseneire, 2012), loans, and other instruments such as loan guarantees or R&D tax credits (Schoening et al., 1998, Trajtenberg, 2001). In general, these interventions are justified on the basis of the market failure (Dasgupta and David, 1994) in which the inability of firms to appropriate all of the benefits of R&D investment results in under-investment relative to the socially optimum.i Evaluations of the effectiveness of these various forms of public support for private R&D and innovation have generally demonstrated positive results in terms of the scale of private R&D investments and innovation outputs (Hsu et al., 2009, Licht, 2003, Luukkonen, 2000).

Yet issues remain in our understanding of the effect of public subsidies on private innovation, predominantly in terms of the mechanisms through which firms benefit from innovation subsidies, and the period over which subsidies continue to have an effect on business innovation. This is despite the fact that evaluations of innovation support measures have become more sophisticated, for example in allowing for the impact of selection bias (Duguet, 2004, Aerts and Schmidt, 2008, Hewitt-Dundas and Roper, 2009), and applying experimental approaches (Reiner, 2011, Bakhshi et al., 2012). Evaluations remain dominated by a short-term focus, however, and an over-emphasis on resource-effects (input additionality) and results-effects (output additionality) with little attention to longer-term learning effects. The short-term horizons, implicit in many innovation policy evaluations are particularly disappointing given the relatively long periods which are often needed for innovations to achieve scale in the market place. For example, recent UK guidelines on the evaluation of publicly funded innovation projects suggest adopting a three-year period for the persistence of benefits in individual enterprise support measures (BIS, 2009, p. 26). Short-term evaluations may also under-estimate the longer-term benefits of innovation support measures through their organisational learning effects (Bartezzaghi et al., 1997, Clarysse et al., 2009, Cohen and

Levinthal, 1989, Jimenez-Jimenez and Sanz-Valle, 2011), and/or wider innovation spillovers (Beugelsdijck and Cornet, 2001). Not capturing these longer-term, or legacy, effects may lead to the benefits of such initiatives being underestimated and subsequently an under-investment in innovation policy. Where such 'policy failure' occurs this may exacerbate the standard 'market failure' which leads firms to under-invest in R&D and innovation due to their inability to appropriate the positive externalities of R&D and innovation (Martin and Scott, 2000, Woolthuis et al., 2005). Alternatively, adopting a short-term perspective may lead to an over-estimation of policy effects where short-term benefits are not sustained in the longer-term (Hewitt-Dundas and Roper, 2011).

In this paper we are interested in the additionality effects of public subsidies for private-sector innovation. Specifically, we are concerned not only with those aspects of additionality which have been widely researched to date, i.e. input and output additionality, but also with identifying firm-level learning effects from innovation support as measured through behavioural additionality (Buiseret et al., 1995). This addresses an identified weakness in the literature with Clarysse et al (2009. 1518) stating that 'the concept of behavioural additionality has not really been tested in empirical studies. As such, it has remained a rather anecdotal observation, without much academic work to underpin its existence or to explain the mechanisms through which it was affected'. Our interest is in exploring the mechanisms through which additionality occurs and also recognising that 'while input and output additionality operate at a point in time, behavioural additionality effects may be expected to endure beyond the period of R&D and to be integrated into the general capabilities of the firm' (Georghiou, 2004, 4). We therefore adopt a long-term perspective in evaluating the legacy effects of public subsidies for private innovation.

Our paper adds to existing knowledge on the effects of public subsidies for innovation in three ways. First, recognising that assessment of the different mechanisms through which behavioural additionality occurs are not well developed and tested (an exception is that by Clarysse et al 2009), we contribute to the evidence on this from an organisational learning perspective. Second, with most additionality assessments focusing on the short-term (Cunningham et al, 2013) we assess not only how behavioural additionality occurs in the longer-term, but also consider the legacy effects of input and output additionality. Thirdly, we consider separately the potentially different legacy effects of public support for R&D and that for new product development.

Our analysis is based on panel data on Irish manufacturing firms, and we focus on the legacy effects of public innovation subsidies at the level of the plant. For example, do publicly supported innovation projects generate behavioural effects which persist beyond the life of the supported project (Aschhoff and Fier, 2005, Clarysse et al., 2009, Falk, 2004, Georghiou, 2004, Kim and Song, 2007)? Or, do publicly supported innovations made in one period provide an enhanced basis for innovation in subsequent periods through quality-ladder type effects (Hewitt-Dundas and Roper, 2009)? Evidence of either would suggest significant legacy effects; evidence of neither would suggest that the effects of public support for innovation are time-limited to the duration of the project and leave no lasting legacy. Both scenarios have potentially significant policy implications. If there are legacy effects, the benefits of innovation policy should be incremental, creating steadily stronger innovating firms, and a strong argument for policy intervention. If additionality is transient the case for innovation policy intervention is weaker.

The remainder of the paper is organised as follows. Section 2 reviews the evaluation literature outlining the alternative mechanisms through which legacy effects might result and how these might affect innovation performance in the post-subsidy period. Section 3 describes the data used in our empirical analysis – the Irish Innovation Panel – and the operationalization of our tests for legacy effects. The tests we propose rely on the notion of the innovation production function, and the intuition that, due to organisational learning, firms which received public support for innovation in a previous period may derive more innovation value from innovation inputs in subsequent periods than firms which had received no prior support. Section 4 of the paper outlines the main empirical results and

Section 5 concludes with a range of conceptual and policy implications.

2. DIMENSIONS OF ADDITIONALITY

Central to the rationale for public policy intervention to support innovation is the notion of 'additionality', i.e. the extent to which additional innovation activity is stimulated by public support (Buiseret et al., 1995, Luukkonen, 2000, Georghiou, 2004). This rationale is based mainly on a neo-classical economics perspective, premised on the notion that additional innovation activity will in turn lead to greater innovation spillovers than would have occurred in the absence of public support (Beugelsdijck and Cornet, 2001, Czarnitzki and Kraft, 2012, De Bondt, 1996). Assessment of the effectiveness of public support has therefore mirrored this rationale and concentrated on measuring additionality in terms of firms' resources (input additionality) and innovation results (output additionality) (Falk 2007)[1]. This has been supplemented in some instances by an assessment of pure and rent-based spillovers to other non-supported organisations (Griliches, 1995), or what Autio et al (2008) refer to as "second-order additionality"[2].

Other perspectives, notably organisational and learning theories, have increasingly emphasised that this neo-classical approach does not capture fully the behavioural effects of public support on firms' innovation capabilities (Busisseret et al 1995, Georgiou 2002, Falk 2007, Clarysse et al., 2009, Hsu et al., 2009, Norrman and Bager-Sjogren, 2010, Afcha Chavez, 2011). Indeed, Georgiou (1997, 2002) argues that public support is less significant in determining if a project will go-ahead, but rather in determining the scale, scope and speed of the project. As such, behavioural additionality occurs alongside other input and/or output

[1] Input additionality adopts a resource-based perspective in examining the extent to which firms increase their private investment in R&D in response to public R&D subsidies (Falk 2007). Output additionality adopts a results-based perspective (ibid.) in terms of the increase in innovation outputs i.e. patents, products etc. or innovation outcomes i.e. sales from new or modified products etc. arising from public support for R&D.
[2] First-order additionality is concerned with direct technological and learning outcomes of R&D subsidies whereas second-order additionality occurs through technological learning and innovation outcomes, typically arising through 'knowledge spill-overs, technology diffusion, and knowledge exchanges within communities of firms' (Autio et al, 2008, 59).

additionality effects. In other words, not only are short-term effects of public support reflected in the resources committed to a project (input additionality), or the results arising from a project (output additionality), but other complementary effects may also exist such as behavioural changes in the innovation process (behavioural additionality). These behavioural changes may, however, be sustained beyond the lifetime of the project as learning effects are integrated and embedded in firms' innovation routines and capabilities. In turn these learning effects may have positive longer-term effects on innovation outcomes.

There is substantial empirical evidence for the positive effect of public subsidies on short-term input and output additionality measures (see for example Aerts and Schmidt, 2008, Aschhoff and Fier, 2005, Buiseret et al., 1995, Czarnitzki and Licht, 2006, Hewitt-Dundas and Roper, 2009, Hsu et al., 2009). However, considerably fewer studies have attempted to assess behavioural additionality (Clarysse et al 2009, Georghiou, 2004). Part of the explanation for this is the 'multi-layered' (Georghiou 2004, 4) nature of behavioural additionality which makes it difficult to determine the mechanisms through which behavioural changes are evident, and the period of time over which their effect persists. Even less attention has been given to the legacy effects of additionality – whether for input, output or behavioural additionality – on longer-term innovation performance. In the following sections we therefore consider in more detail each type of additionality and their potential legacy effects.

2.1 Input Additionality

The expectation of input additionality is central to the neo-classical rationale for public support for innovation. Here, resources are provided to firms to undertake activities that would not otherwise have occurred. Input additionality has therefore been understood as a quantitative measure, determined by 'whether for every Euro provided in subsidy or other assistance, the firm spends at least an additional Euro on the target activity' (Georghiou 2002, 1). Naturally this has simulated debate about the extent to which public investment acts as a complement to private investment or as a substitute, crowding-out private expenditure (David et al 2000). Reviews of crowding-out effects (David et al 2000, Garcia-Quevdeo 2004, Aerts and Schmidt 2008) find mixed results, although Aerts and Schmidt (2008) conclude that the majority of studies find little crowding out effect.

Common to these empirical studies of crowding-out has been a focus on short-term effects. However, public subsidies may also lead to longer-term legacy effects which influence innovation outcomes in subsequent periods. This may occur where public support for innovation has a legacy of cost or quality impact on the in-house R&D resources which a firm has available and deploys. For example, Czarnitzki and Licht (2006) found that R&D subsidies raised R&D intensity (i.e. R&D spend per unit of sales) from 2.3 per cent to 6.4 per cent with potentially significant legacy impacts in terms of infrastructure or equipment. Therefore, public support in one period may enable a firm to invest in R&D infrastructure or equipment which may enhance the innovation value of future R&D investments. In other words, public innovation subsidies may lead to qualitative improvements in R&D capacity such that for every Euro invested by a firm in R&D in subsequent periods the innovation outputs are greater than those achieved by firms which did not previously receive public subsidies. This leads to our first proposition:

> Proposition 1: Past receipt of public subsidies for innovation will increase the innovation returns from current R&D investments.

2.2 Output additionality

Where innovation investment occurs there is an expectation of outputs or results (Falk, 2004). Output additionality relates to those outputs from the innovation process which would not have occurred in the absence of public subsidies (Luukkonen 2000, Georghiou 2002). At least two difficulties have been identified relating to the identification and measurement of output additionality. First, the relationship between innovation investment and outputs is neither linear nor independent of other innovation investments.

For example, from a structuralist-evolutionary perspective Bach and Matt (2002) argue that there is not a direct and unambiguous relationship between innovation inputs and outputs. Similarly, Clarysse et al (2009) suggest the possibility that both intra- and inter-organisational knowledge spillovers may result from any innovation project creating difficulties in isolating the effects of public and private investments.

Second, there is no universally accepted measure of innovation output additionality (Clarysse et al 2009). As with input additionality, assessments of output additionality have typically been quantitative including direct indicators such as patents, downstream indicators such as the share of sales from new and improved products, and also indirect indicators including value added, profitability etc. Virtually no consideration has been given to qualitative aspects of output additionality and how these might influence innovation outcomes over the longer-term. For example, public subsidies for innovation may enable firms to introduce new, higher quality products or accelerate their NPD processes (Luukkonen, 2000). It may, however, take longer than the period during which public support is received to achieve these outputs and therefore short-term evaluations may underestimate project results. Even where these outputs are achieved in the funding period, the creation of more novel, more complex or more successful products than otherwise may have legacy effects leading to a 'quality ladder' in subsequent periods (Grossman and Helpman, 1991)[3]. For example, Alecke et al. (2012) suggest that for firms receiving R&D subsidies in East Germany the probability of making related patent applications – an indication of innovation quality – rises from 20 to 40 per cent. The implication is that public innovation subsidies may generate legacy effects on future innovation outcomes through short-term improvements in technology or product cost which are greater in firms which received innovation subsidies. This suggests our second proposition:

[3] Such quality ladder effects have been shown to be important in determining the duration of exporting (Chen, 2012).

> Proposition 2: Past receipt of public subsidies for innovation will increase the value of past innovation as the basis for current innovation.

In terms of the innovation production function this means that the relationship between current innovation outputs and lagged innovation outputs will be positively moderated by firms' receipt of public subsidies in the previous period (Figure 1).

2.3 Behavioural additionality

In recent years, the range of potential effects that have been considered in evaluating the effectiveness of public subsidies for innovation has extended beyond quantitative indicators of input and output additionality to include potential effects on the innovation capabilities of the firm (Afcha Chavez, 2011, Clarysse et al., 2009, Hsu et al., 2009, Norrman and Bager-Sjogren, 2010). In the evaluation literature this is discussed in terms of behavioural additionality (Buisseret et al 1995, Davenport et al 1998, Georghiou 2002). However, a lack of consensus as to what is understood by the notion of behavioural additionality has led to a wide variety of assessment approaches (Cunningham et al 2013). Indeed the OECD's (2006) pilot project identified seven dimensions of behavioural additionality ranging from project acceleration, scale and scope to the formation of collaborative networks and change in management practices. Roper et al. (2004) also conclude that innovation subsidies may lead to increments in firms' private knowledge stock, development of firms' capabilities for subsequent R&D productivity, and benefits arising from the commercial exploitation of R&D[4].

Recently, efforts to examine behavioural changes have drawn on an organisational learning perspective (Bontis 1998, Clarysse et al 2009, Knockaert et al 2013). Knockaert et al (2013), although focusing on the effect of intermediary organisations on firms' innovation behaviour, consider behavioural additionality in terms of improvements in firms'

[4] Generally these changes are perceived as being desirable however there is also the potential for undesirable behaviours to emerge through, for example, inefficient routines, risk taking etc.

cognitive capacity (Bach and Matt 2002), defined as 'the positive impact on competencies, expertise and networks' (Knockaert et al 2013, 3). These three dimensions of cognitive capacity mirror closely the approach adopted by Clarysse et al (2009) in examining the effect of direct public support (R&D subsidies) on organisational learning through congenital learning (competencies), experiential learning (expertise) and inter-organisational learning (networks). However, both of these studies of additionality draw on the well-established organisational learning literature with Bontis (1998) conceptualising intellectual capital in an organisation as the sum of: human capital i.e. congenital learning (Clarysse et al 2009) or competencies (Knockaert et al 2013); structural capital relating to the embedding of organisational knowledge through routines i.e. experiential learning (Clarysse et al 2009) or expertise (Knockaert et al 2013); and customer capital which Bontis (1998) refers to as knowledge embedded outside the firm and developed through inter-organisational learning (Clarysse et al 2009, Knockaert et al 2013). Following Clarysse et al (2009) we consider behavioural additionality through the lens of organisational learning, and discuss each of these three learning mechanisms (i.e. congenital, inter-organisational and experiential) in turn.

2.3.1 Congenital additionality

Firms' 'cognitive capacity' (Bach and Matt 2003, Knockaert et al 2013) is comprised of two dimensions: human capital which Bontis (1998, 65) refers to as 'the sheer intelligence of the organizational members' and inter-organisational networks. In order words, cognitive capacity refers to the internal knowledge (intellectual) stock in a firm and the enhancement of this through external knowledge networks. From an organisational learning perspective, congenital learning is then defined as the individual's education and experience at the individual knowledge node, i.e. that internal to the mind of the employee (Bontis 1998). At the organisational level, the stock of human capital and the potential for congenital learning is therefore measured as the sum of employees' education and experience.

Critical to our concern with behavioural additionality through organisational learning is the path dependent and cumulative nature of congenital learning. A number of other studies have found evidence that public subsidies for innovation lead to more challenging research being undertaken. For example, of those firms involved in the R&D Start Programme in Australia (DITRA 2006), 78 per cent undertook more challenging activities than would have occurred in the absence of the subsidy. Similarly, in Germany (Fier et al 2006), funding for R&D projects led to 60 per cent of firms undertaking more technically challenging projects with similar figures being reported for firms engaging in the Finish programmes (Hyvärinen et al, 2006). This suggests that firms undertaking publicly subsidised innovation may develop new or improved skill sets which add value to *subsequent* innovation projects (Leiponen, 2005). Indeed, Sakibara (1997) found that the development of managers' skills were the most important benefit which firms derived from involvement in publicly funded R&D projects. The implication is that public subsidies for innovation may lead to congenital learning and improvements in the quality or skills of firms' human resources with potentially positive legacy effects. Therefore:

> Proposition 3: Past receipt of public subsidies for innovation will increase the innovation returns from current human capital.

2.3.2 Inter-organisational additionality

Firms' innovation outputs depend increasingly, not only on the quality and scale of their internal resources but also on their external networks and operating environment (Chesborough, 2003, Chesborough, 2006). The asymmetric nature of firms' resources and competencies create the potential for learning (Dosi 1997) through inter-organisational collaboration and the transfer of tacit and explicit knowledge, also referred to as 'vicarious learning' (Ingram and Baum, 1997). Learning may be manifest in various ways, for example, financially where external linkages increase firms' ability to appropriate the returns from innovation, by stimulating creativity, reducing risk, accelerating or upgrading the quality of the innovations made, and/or signalling the quality of firms' innovation activities (Powell 1998). External links may also lead to learning as firms search the technological environment systematically, permitting access to improved technology developed elsewhere (Laursen and Salter, 2006).

A review of R&D programme evaluations across eleven countries concluded that firms in receipt of public support were more likely to collaborate with other businesses (OECD 2006). In other words, innovation support led to the development of new inter-organisational collaborations with the associated potential for knowledge transfer and learning. This suggests that where public subsidies for innovation encourage firms to broaden or deepen their external innovation linkages this may generate inter-organisational additionality. As with congenital learning, inter-organisational learning is cumulative and path dependent with the acquisition of new knowledge dependent on previously acquired knowledge (Powell et al 1996)[5]. The implication is that public subsidies for innovation may increase the effectiveness or depth of firms' external linkages generating positive legacy effects. Therefore:

> Proposition 4: Past receipt of public subsidies for innovation will increase the innovation returns from current inter-organisational linkages.

2.3.3 Experiential additionality

The third mechanism through which firms may experience persistent behavioural additionality effects from public subsidies for innovation, is through experiential learning. In the innovation literature discussion of experiential learning has largely been in terms of dynamic capabilities (Zhara and George 2002) whereby firms reconfigure the routines and processes used to acquire, assimilate, transform and exploit knowledge in response to changing technological and market environments. However, the organisational learning literature drew attention much earlier to the

[5] However, recent studies have also identified limits to the benefits of openness as the number of firms' external relationships increases (Ahuja and Katila, 2001, Leiponen and Helfat, 2010).

importance of ‘learning new knowledge and discarding obsolete and misleading knowledge (Hedberg 1981, 3), or ‘reducing or eliminating pre-existing knowledge or habits that would otherwise represent formidable barriers to new learning’ (Newstrom 1983, 36). This ability to reconfigure routines and processes is particularly important in volatile technological or market conditions with Cegarra-Navarro and Wensley (2009, 534) stating that faced with such turbulence, the ‘effective transfer and transformation processes for congenital knowledge might be counterproductive if they operate uncritically’.

In the innovation literature, both conceptual and empirical analysis of experiential learning is limited (Allen and Holling, 2010, Mugdh and Pilla, 2011). More commonly, studies have focused on the extent to which firms apply for and receive subsequent public innovation subsidies (Clarysse et al 2009, Falk 2006, DITRA 2006), however, only partially reflects the the essence of experiential learning as ‘embedded within the routines of an organization… internal to the firm but external to the human capital nodes’ (Bontis, 1998, 66). Other innovation studies, albeit neglecting the effect of public support, have discussed the relationship between innovation and perceived environmental uncertainty (Freel, 2005) and innovation persistence (Raymond et al., 2010, Roper and Hewitt-Dundas, 2008). Strategic perspectives, for example, suggest that market turbulence may create new competitive spaces as rivals close or retrench (Caballero and Hammour, 1994), potentially increasing the returns to innovation (Todd, 2010). Indeed, some firms may actively seek to create market turbulence by engaging in disruptive innovation in order to establish a position of market or technological leadership (Anthony et al., 2008).

Despite the lack of conceptual and empirical analysis of experiential additionality, evidence demonstrating that firms undertake larger or more technologically advanced projects with public subsidies creates the potential for experiential learning effects, or experiential additionality. In other words, such innovation projects may lead to changes in existing processes and routines and/or the introduction of new ones through exploration and reflection. Dependent on firms’ ability to capture this learning (De Holan and Philips 2004), public subsidies for innovation may mean that firms are able to reconfigure their resources and innovation processes in subsequent periods. That is, the legacy effect of experiential learning associated with receipt of innovation subsidies will be greater than for those firms without prior public support:

> Proposition 5: Past receipt of public subsidies for innovation will increase the innovation returns from current organisational routines

3. DATA AND METHODS

Our empirical analysis is based on data from the Irish Innovation Panel (IIP) which provides information on the innovation activities of Irish manufacturing plants over the period 1991 to 2011. More specifically, the IIP comprises seven surveys or waves conducted using similar survey methodologies and questionnaires with common questions (Roper et al, 1996, Roper and Hewitt-Dundas, 1998, Roper and Anderson, 2000, Hewitt-Dundas and Roper, 2008). Each survey covers the innovation activities of manufacturing business units with 10 or more employees over a three-year reference period. The resulting panel is highly unbalanced reflecting non-response in individual surveys but also the opening and closure of business units over the 21 year period covered. The panel contains 5,594 observations on 3,254 individual business units representing an overall response rate of 32.1 per cent. Variable definitions are included in Annex 1 and correlations in Annex 2.

For the current analysis we focus on two innovation variables. First, a 'narrow' definition of innovative sales calculated as the proportion of plants' total sales (during the final year of each three-year reference period) derived from products newly introduced during the previous three years. Secondly, a 'broad' measure of innovative sales defined as the proportion of plants' sales accounted for by newly introduced *and* improved products. Both of these variables reflect not only plants' ability to introduce new/improved products to the market but also their short-term commercial success. For the estimation sample used in this paper (see below) 12.3 per cent of plants' sales were derived from newly introduced products, while 21.4 per cent were derived from new and improved products (Table 1)[6]. Standardly, we model the determinants of these two innovation sales measures using an innovation production function, which relates innovation outputs to the inputs to the innovation process (Griliches, 1995, Love and Roper, 2001, Laursen and Salter, 2006). For example, if I_i is an innovative sales indicator for firm i, the innovation production function can be written as:

$$I_i = \beta_0 + \beta_1 I_{it-1} + \beta_2 RD_i + \beta_3 SK_i + \beta_4 XS_i + \beta_5 EN_i + \beta_6 RI_i + \beta_7 PS_i + \delta_i \qquad (1)$$

Where: RD_i are plants' investments in R&D, SK_i are skills inputs into innovation, XS_i represents external knowledge search or openness, EN_i is a set of indicators of plants' business environment, and RI_i is a set of other plant level control variables.

Also, in equation (1), let PS_i be a binary indicator of whether a plant received public subsidies for innovation. In both Ireland and Northern Ireland innovation subsidies have been an important element of industrial development policy over the last two decades. In Ireland, measures to support innovation in externally-owned firms have been operated primarily through the Irish Development Agency (or IDA), with support for locally-owned firms operated by Enterprise Ireland (Hewitt-Dundas and Roper, 2008). Typically these measures have involved grant support which has subsidised a proportion of the cost of an innovation project. In Northern Ireland, public support for innovation has been operated primarily through Invest Northern Ireland and, before 2001, the Industrial Research and Technology Unit (IRTU) (Cooke et. al. 2003, Roper, 2009).

[6] Correlations between the two innovation output variables are strong, however, (correlation coefficient is 0.805) suggesting firms which perform well on the narrow innovation measure also tend to perform well on the broader indicator of new and improved products.

Again, innovation support measures have been predominantly grants, providing subsidies to particular innovation activities[7]. In the IIP surveys, plants are asked to indicate whether they have received government subsidies for various activities over the last three years including training, marketing activity etc. Here, we are primarily concerned with two questions which ask plants to indicate first, whether they 'have received government support for product development over the last three years', and, second whether they have received 'government support for R&D not linked to any specific product development'. Overall, 21.4 per cent of plants reported receiving support for new product development (NPD), an average of 21.7 per cent in Northern Ireland and 21.3 per cent in Ireland (Table 1)[8]. A smaller proportion of firms – 11.8 per cent – reported receiving support for R&D.

Here, we are interested in the legacy effects of public subsidies from earlier periods[9]. For plants which received innovation subsidies in previous periods, these legacy effects may increase the innovation benefits derived from innovation inputs in the current period relative to those plants which had no prior subsidy. For example, congenital additionality – learning effects - may enhance the innovation capabilities of graduate employees, while legacy input additionality effects may enhance the contribution to innovation of current R&D investments.

[7] In other papers we have documented in detail the development of innovation and R&D policy in Ireland and Northern Ireland. See in particular: Hewitt-Dundas and Roper (2009), O'Malley et al. (2008), (Roper, 1998), Hewitt-Dundas et al. (2005).

[8] The correlation between receiving public support for NPD in the current period and previous period was 0.336 (Northern Ireland, 0.316, Ireland, 0.349) in Ireland. Essentially similar results have been noted elsewhere. Dugeuet (2004) noted that in France among firms receiving R&D subsidies in 1996, 76 per cent were also subsidised in 1997. Similar results are evident in Germany for the Direct R&D Project Funding Scheme (Aschhoff, 2010).

[9] There is substantial evidence of this type of short-term additionality effect from innovation policy (Aerts and Schmidt, 2008, Aschhoff and Fier, 2005, Buiseret et al., 1995, Czarnitzki and Licht, 2006, Hewitt-Dundas and Roper, 2009, Hsu et al., 2009). Strong and significant short-term additionality effects are also evident in our data controlling for sample selection and using a range of estimation approaches (instrumental variables, matching estimators). Results are available on request from the authors.

To test the hypotheses, we define PS_{it-1} as an indicator variable which takes value 1 if the firm received public support for innovation in the previous wave of the IIP and 0 otherwise[10]. Then, to evaluate Hypothesis 2, the potential for legacy output additionality effects, we use PS_{it-1} to partition the regressor I_{it-1} between those firms which did and did not receive innovation subsidies in the previous period and then compare the two estimated coefficients. This amounts to estimating:

$$I_i = \beta_0 + \beta_1^A I_{it-1} \times PS_{it-1} + \beta_1^B I_{it-1} \times (1 - PS_{it-1}) + \beta_2 RD_i + \beta_3 SK_i + \beta_4 XS_i + \beta_5 EN_i + \beta_6 RI_i + \beta_7 PS_i + \delta_i$$

(2)

and then testing whether $\beta_1^A > \beta_1^B$. If this inequality holds it suggests legacy output additionality effects. Essentially similar tests then apply to the other hypotheses.

Operationalizing equation (2) for the other hypotheses draws on a range of other data from the IIP. To reflect the potential for legacy input additionality effects we consider its effects on the innovation benefits of plants' in-house R&D, a factor which has been linked positively to innovation success by previous studies (Love and Roper, 2001, Love and Roper, 2005, Griffith et al., 2003). In the IIP an average of 46.1 per cent of plants were undertaking in-house R&D, a proportion which varied relatively little over the survey period (Hewitt-Dundas and Roper, 2008). The potential for legacy congenital additionality effects is measured by their effects on the innovation benefits of two human capital variables: the proportion of plants' workforces with a degree and whether plants reported that a lack of technical skills was a barrier to innovation. Both variables have previously been linked to innovation success in studies using an innovation production function approach (Leiponen, 2005, Freel, 2005, Hewitt-Dundas, 2006). On average across the IIP, 9.7 per cent of plants' workforces had a degree

[10] In other words, where plants received public support for NPD or R&D in the previous wave of the survey 4-6 years previously.

level qualification, while 37.2 per cent of plants reported that technical skills were a 'significant' or 'very significant' barrier to innovation (Table 1)[11].

Legacy inter-organisational additionality effects reflect the extent to which plants' innovation networks may be enhanced or developed as a result of prior innovation subsidies (OECD, 2006). Here, legacy effects require that the innovation benefit of a given level of network activity – reflected in the estimated coefficients in the innovation production function - is greater where a plant received previous public subsidies for innovation. We include two measures: whether a lack of technical information was a significant barrier to plants innovation activity, and the 'breadth' of plants' innovation network activities or 'openness' measured as per Laursen and Salter (2006). This is an index which takes values between one and eight depending on the number of different types of innovation partners with which a plant is engaging. In the models we also include a square of this variable to reflect the standard finding of an inverted-U shaped relationship between innovation outputs and network breadth (Leiponen and Helfat, 2011)[12]. Finally, to capture the potential for legacy experiential additionality effects we consider two measures which reflect environmental barriers to business innovation: regulatory or legislative factors and a lack of finance for innovation. In both cases we would anticipate that the provision of public subsidies in one period might lead to organisational learning effects which moderate the effect of these innovation barriers in subsequent periods.

In the estimated models we also include two other control variables which give an indication of the scale of plants' resources – size – as well as the potential for the cumulative accumulation of knowledge capital by older plants (Klette and Johansen, 1998) and plant life-cycle effects (Atkeson

[11] In the IIP plants were asked to indicate the importance of various barriers to innovation on a 1 to 5 Likert scale. In the operationalization of equations (1) and (2) these variables were transformed into binary indicators taking value one if an innovation barrier was said to be 'significant' or 'very significant' and zero otherwise.

[12] Interestingly, the potential for organisational learning in plants' innovation networking activity has recently been examined by Love et al. (2013). Their analysis, using the same data set as that used here, suggests positive evidence of learning effects and perhaps the potential for inter-organisational legacy effects.

and Kehoe, 2005). Sector dummies at the 2-digit level and wave dummies are also included in each model (but not reported). Our estimation approach is determined primarily by the nature of our innovation output variables – the percentage of innovative sales. Panel data tobit models are therefore used to estimate models of equations (1) and (2)[13].

4. EMPIRICAL RESULTS

Baseline models of the innovation production function (Equation 1) are reported in Table 2 for the narrow and broad measures of innovative sales. Results are largely consistent between the two innovation measures, and RHS variables largely take the expected sign. Innovation outputs are positively related to R&D suggesting significant input effects (Love and Roper, 2001, Love and Roper, 2005, Griffith et al., 2003). Last period's level of innovation sales is also significant in both models suggesting a significant degree of autocorrelation in innovative sales. Levels of graduate employment are also positive but insignificantly related to both innovation indicators, while a lack of technical skills has a weak negative effect on innovative sales (Table 2). Both suggest a positive – if weak – link between firms' human capital resources and innovation (Leiponen, 2005, Freel, 2005, Hewitt-Dundas, 2006). Openness indicators have the expected inverted-U shape relationship to both the narrow and broad measure of innovative sales (Laursen and Salter, 2006, Leiponen and Helfat, 2011). Business environment effects are weaker, with neither legislative restrictions nor a lack of finance for innovation having significant effects. The two control variables have the expected signs: larger firms are generally more innovative, while older plants have lower levels of innovative sales (Table 2).

Models designed to test each of the hypotheses are reported in Table 3 for the narrow measure of innovative sales, and Table 4 for the broad measure. Models reported relate to the legacy effects of public subsidies

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[13] Note here that we are not interested in the treatment term on current innovation subsidies (β_7) which reflects short-term additionality. Instead this acts as control variable in our tests for legacy effects from prior public support.

for new product development (NPD) activity. Our first hypothesis relates to the potential for legacy input additionality effects and, in particular, whether the innovation benefits of plants' R&D investments are enhanced by prior subsidies for NPD. Partitioning R&D investment as suggested in equation (2) suggests that R&D inputs play an important role in innovation regardless of whether a plant had previously received public subsidies for NPD or not (Model 1, Tables 3 and 4). The coefficients also suggest that the innovation benefits of R&D are marginally greater for both the narrow and broad innovation sales measures where a plant had previously received NPD subsidies (Model 1, Tables 3 and 4). Wald tests of the restriction $\beta_1^A = \beta_1^B$, however, suggest these differences are insignificant (Table 5). Our results therefore provide no evidence of legacy input additionality effects from NPD subsidies for either innovation measure and therefore no support for Hypothesis 1.

Hypothesis 2 relates to potential legacy output additionality effects. For both the narrow and broad measures we find that lagged innovative sales effects prove important regardless of whether a plant had previously received NPD subsidies (Model 2, Tables 3 and 4). The Wald tests suggest significant differences between the estimated coefficients on the partitioned lagged innovative sales measure but only for the narrow measure of innovative sales (Table 5). One possible explanation is that public subsidies are enhancing the quality or novelty of firms' innovative output in the previous period, which then provides an enhanced basis for subsequent innovation. Such innovation quality effects from public support for NPD have been recognised in a number of other studies (Bérubé and Mohnen, 2009, Hewitt-Dundas and Roper, 2009). However, our evidence here suggests that the effects of these innovation quality improvements persist, giving previously subsidised plants longer-term strategic advantages perhaps by helping them to achieve positions of technology or market leadership or first-mover advantage. Alternatively, public support for NPD may be allowing firms to invest in platform technologies which may allow the development of variants in future periods (Pasche and Magnusson, 2011). Or, by enhancing the market reputation of an enterprise with consumers, firms' innovation may be more successful in the market place (Henard and Dacin, 2010). Whatever the explanation, our results provide some support for Hypothesis 2 and legacy output additionality effects from NPD subsidies.

Hypothesis 3 relates to congenital additionality and the potential legacy effects of public NPD subsidies on the innovation benefits of plants' human capital. As in the baseline models (Table 1) we find little evidence that levels of graduate employment have any significant effect on innovation outputs regardless of whether plants had, or had not, previously received NPD subsidies (Model 3, Tables 3 and 4). There is clear evidence, however, that prior public support for NPD is significant in offsetting the effect of a lack of technical skills on both measures of innovative sales (Model 3, Tables 3 and 4). Two possibilities are evident here. First, it may be that the experience of working on publicly supported innovation projects has given plants' senior management a better understanding of the quality of their skill base for innovation. This may be reducing management perceptions of any lack of technical skills. A more likely scenario, however, is that plants' prior experience of publicly funded innovation projects has resulted in the type of learning-by-doing effects noted by Sakakibara (1997). In statistical terms, a joint test of the equality of the coefficients on the two human capital measures is rejected for both the narrow and broad measures of innovative sales (Table 5). This provides strong support for Hypothesis 3 and legacy congenital additionality effects from NPD subsidies.

The potential for legacy inter-organisational additionality effects is captured in our innovation production functions by two variables: the breadth of plants' co-operative relationships for innovation and a perceived lack of technical information. In our baseline models (Table 2) plants' co-operative relationships play a significant role, with evidence of an inverted-U shape relationship with innovation (Laursen and Salter, 2006, Leiponen and Helfat, 2010). We also find a negative, albeit insignificant, innovation effect associated with a perceived lack of technical information (Table 2). The innovation effects of both variables differ markedly, however, depending on whether or not plants had previously received subsidies for NPD (Model 4, Tables 3 and 4): co-operative relationships for innovation only prove beneficial for innovation when a plant received prior innovation subsidies; and, prior subsidies also offset the negative effect of a lack of technical information. The implication is that inter-organisational relationships have stronger innovation benefits where firms have received NPD subsidies, a suggestion confirmed by the relevant Wald test (Table 5). One possible explanation is that publicly subsidised NPD projects encourage firms to develop new innovation partnerships (OECD, 2006), and that as these relationships mature they provide increasing innovation benefits (Baum et. al. 2012). Alternatively, public subsidies for NPD may have a signalling effect, making it easier for plants to develop future innovation partnerships and/or access external information sources (Kleer, 2010). Either mechanism could generate the legacy inter-organisational additionality effects we observe.

Our final Hypothesis (5) relates to experiential additionality, the idea that organisational learning during a publicly subsidised NPD project may allow a plant to develop improved routines or processes. Better routines may then help to minimise the innovation impacts of either financial constraints or regulatory restrictions. Results here are rather mixed with neither aspect of the business environment having a significant effect on innovation outcomes in the baseline models (Table 2). Legacy experiential additionality effects are also only evident in terms of regulatory barriers with no significant finance effect for either the narrow or broad measure of innovative sales (Model 5, Tables 3 and 4). A joint test of the equality of the coefficients on the two experiential additionality measures is rejected only in the case of the narrow measure of innovative sales providing only partial support for any legacy experiential additionality effects from NPD subsidies (Table 5).

So far we have considered the legacy effects of public subsidies for NPD. Repeating the analysis for prior receipt of public subsidies targeted at more basic R&D (not linked to any specific product/service) suggests strikingly different results, however.[14] For NPD subsidies the most consistent legacy effects are congenital and inter-organisational, both of which reflect improvements in the innovation capabilities of subsidised plants. For R&D subsidies, however, neither of these behavioural additionality effects are significant (Table 5). Here, instead, here the most consistent legacy effect operates through prior innovation or output additionality. One possibility is that this contrast reflects the nature of the innovation activity being supported by each type of subsidy: R&D subsidies are likely to support more basic research activity, with projects being undertaken predominantly by either scientific or technical staff; Subsidised NPD projects on the other hand are likely to involve a wider range of skill groups with the potential for a broader legacy of capability development.

5. CONCLUSIONS

Two main empirical conclusions follow from our study. First, our study suggests the significance of the legacy effects of innovation subsidies, reinforcing other international evidence of the positive short-term additionality of such public support for innovation (Aerts and Schmidt, 2008, Aschhoff and Fier, 2005, Buiseret et al., 1995, Czarnitzki and Licht, 2006, Hewitt-Dundas and Roper, 2009, Hsu et al., 2009). The implication is that any assessment of the benefits of innovation support based solely on its short-term impacts is likely to under-estimate the total benefits of such support to recipient firms. This supports other suggestions (Martin and Scott, 2000, Woolthuis et al., 2005) that undertaking innovation policy evaluation with a short-term perspective on its benefits may result in policy failure which lead to an under-investment in public innovation support, exacerbating market or system failures. This effect is likely to be more serious where short-term evaluations also under-estimate the wider social

[14] Full details of the analysis for R&D subsidies – the equivalents of Tables 3 and 4 – are available from the authors on request.

benefits of innovation support, benefits which are also only likely to be observable in the longer-term (Beugelsdijck and Cornet, 2001).

Second, our study identifies clear contrasts between the types of legacy effect which arise from different types of innovation subsidies: NPD subsidies lead to a legacy of broadly based capability development, while R&D subsidies result only in legacy effects mediated through prior innovation. The suggestion is that the legacy effects of each type of subsidy operate through very different mechanisms. Legacy effects from NPD subsidies appear largely behavioural, with subsidies generating longer-term benefits through increases in the innovation benefits of plants' human capital and network relationships. For R&D subsidies the key legacy effect operates through a process of product quality improvement rather than through a legacy of improved innovation capabilities. R&D support in particular might be expected to contribute in the longer-term to the quality of firms' product portfolio through a quality ladder effect and hence to the longer term success of firms' innovation (Grupp and Stadler, 2005) and exporting (Chen, 2012).

From a policy perspective, our results suggest that the legacy effects of innovation subsidies extend beyond the generally anticipated behavioural effects and include legacy output additionality effects. The potential for such legacy effects suggests that implementing measures to help firms capture the potential longer-term benefits of publicly supported innovation projects may be helpful. In terms of business finance, for example, there has recently been considerable discussion of intelligent finance or intelligent capital and the notion that venture capital firms often provide both finance and managerial expertise to their client companies. In terms of NPD or R&D support the analogue – intelligent innovation policy – might provide technology or innovation management support to firms alongside any subsidy support to help firms capture and embed potential strategic lessons (Technology Strategy Board 2013).

Our study suffers from a number of limitations. First, it is restricted to a single geographic area and covers only manufacturing firms. This may be imparting a bias to the results and it would be useful therefore to examine the profile of legacy effects from innovation subsidies for different groups of firms. Second, while the literature around behavioural additionality has developed rapidly over recent years there has been less discussion of the different dimensions of output additionality. How does this work? Is this a product quality or novelty effect? Or, does this effect relate to firms' development of new platform technologies? Further research examining these alternative types of output additionality would be valuable in understanding the full range of legacy effects from innovation support. Third, because of the structure of the IIP which focuses on three year reference periods, our analysis is restricted to the legacy effects of innovation subsidies which occur in the period 4 to 6 years after the initial support was provided. Long product development cycles in some industries, however, may make even this timescale too short and even longer-term follow-ups of innovation support may help to clarify the full range of benefits from such interventions. Finally, it is worth noting that our analysis also focuses specifically on the legacy benefits for the subsidised organisation itself. However, there may well be wider economic or social benefits from public R&D subsidies which would also need to be taken into account in order to capture the full range of benefits from such support (Roper et al, 2004). Accounting for these benefits may help to provide a more comprehensive view of the social and economic returns to innovation subsidies.

Figure 1: Research model

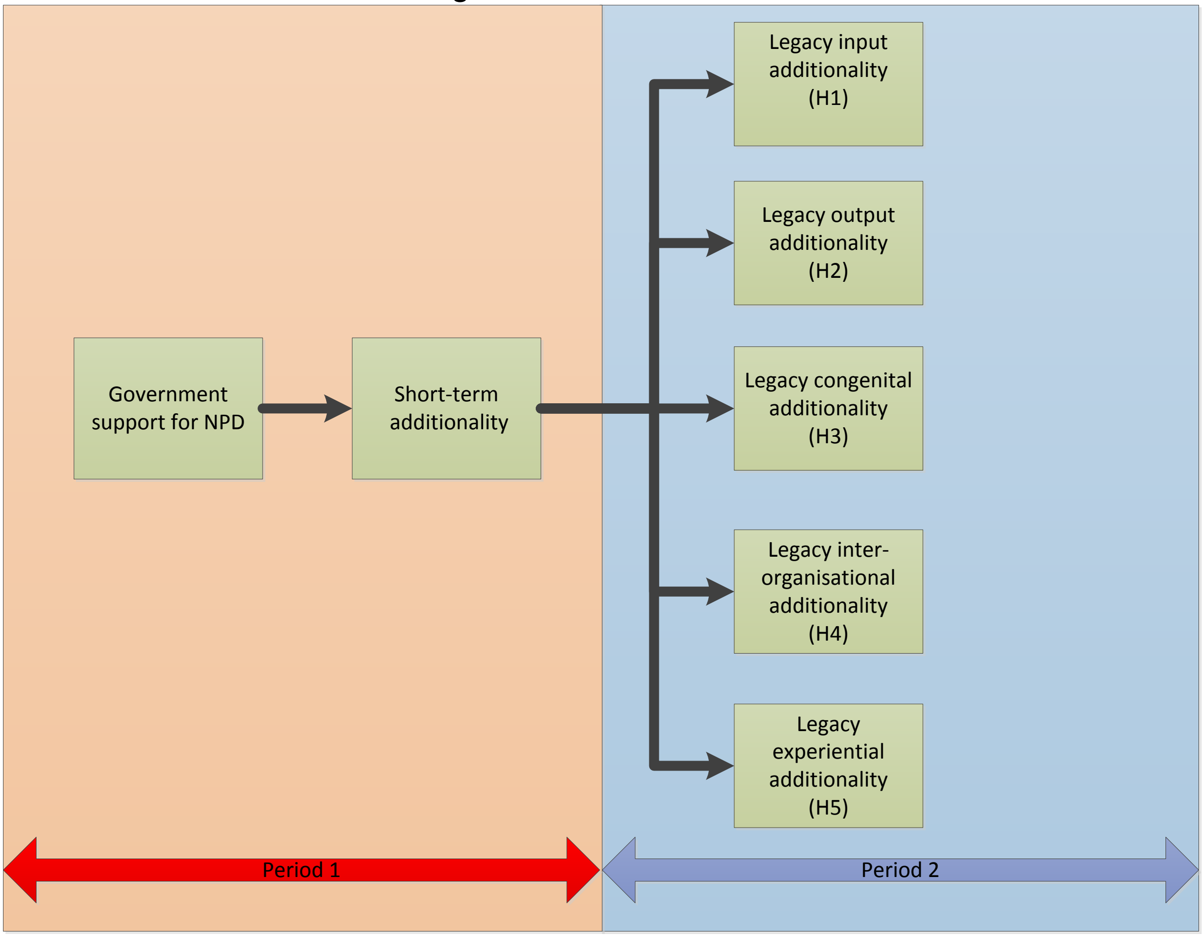

Table 1: Sample Descriptives for estimation sample

|	No. of observations	Mean	Std. Dev.
Innovation Measures			
Sales of new products (percentage of sales)	1678	12.293	19.766
Sales of new and improved products (percentage of	1674	21.355	28.299
Public support indicators			
Public support for NPD	1765	0.214	0.410
Public support for R&D	1769	0.118	0.322
Legacy measures			
In-house R&D (yes/no)	1776	0.461	0.498
Workforce with degree (percentage of workforce)	1696	9.695	12.719
Innovation barrier: Technical skills (yes/no)	1798	0.372	0.483
Breadth of external search (number of partner types)	1764	1.190	1.879
Innovation barrier: Lack technical information (yes/no)	1764	4.946	11.124
Innovation barrier: Regulatory or legislative factors	1798	0.351	0.477
Innovation barrier: Lack finance for innovation	1798	0.383	0.486
Control variables			
Plant employment	1767	77.760	236.752
Plant vintage (years)	1794	32.566	30.037

Source: Irish Innovation Panel, waves 2-7 of the survey are included. Observations are weighted to give representative results. Observations are included only where a lagged observation is available to allow estimation of legacy effects.

Table 2: Tobit models of percentage of innovative sales: baseline models

	New product sales	New and improved product sales
Public support for NPD	4.878**	6.466**
	(1.928)	(2.667)
New product sales (-1)	0.339***	
	(0.041)	
New and improved sales (-1)		0.317***
		(0.043)
In-house R&D	14.731***	24.891***
	(1.776)	(2.462)
Workforce with degree	0.061	0.057
	(0.064)	(0.089)
Innovation barrier: Technical skills	-3.751*	-4.679*
	(2.024)	(2.819)
Breadth of search	3.025***	6.439***
	(1.087)	(1.515)
Breadth of search squared	-0.16	-0.528**
	(0.179)	(0.249)
Innovation barrier: Lack tech. info.	-1.835	-4.812
	(2.219)	(3.086)
Innovation barrier: Regulatory factors	-1.662	0.086
	(1.985)	(2.745)
Innovation barrier: Lack finance	1.578	1.621
	(1.743)	(2.409)
Employment (log)	0.73	2.382**
	(0.839)	(1.154)
Plant vintage	-0.071***	-0.146***
	(0.027)	(0.037)
Number of observations	1519	1513
Equation χ^2	439.834	572.246
BIC	8622.955	9374.657

Source: Irish Innovation Panel, waves 2-7 of the survey are included. Observations are weighted to give representative results. Observations are included only where a lagged observation is available to allow estimation of legacy effects. Coefficients reported are marginal effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All models include a set of (10) sectoral and wave dummies (not reported).

Table 3: Estimating additionality effects on new product sales from NPD support

	New product sales	New product sales	New product sales	New product sales	New product sales
	(2)	(1)	(3)	(4)	(5)
In-house R&D		15.029***	13.567***	14.619***	14.814***
		(1.766)	(1.839)	(1.759)	(1.767)
New product sales (-1)	0.306***		0.293***	0.296***	0.296***
	(0.041)		(0.041)	(0.040)	(0.041)
Innovation barrier: Technical skills	-3.429*	-3.565*		-3.475*	-3.632*
	(2.006)	(2.001)		(1.995)	(2.001)
Workforce with degree	0.054	0.069		0.072	0.071
	(0.064)	(0.063)		(0.063)	(0.063)
Breadth of search	3.040***	3.072***	2.757**		2.920***
	(1.080)	(1.075)	(1.078)		(1.077)
Breadth of search squared	-0.184	-0.175	-0.154		-0.155
	(0.178)	(0.177)	(0.177)		(0.177)
Innovation barrier: Lack tech. info.	-1.522	-1.565	-1.141		-1.199
	(2.198)	(2.193)	(2.191)		(2.197)
Innovation barrier: Regulatory factors	-2.364	-2.564	-2.285	-2.094	
	(1.972)	(1.972)	(1.963)	(1.967)	
Innovation barrier: Lack finance	1.958	1.796	2.05	1.853	
	(1.733)	(1.729)	(1.729)	(1.722)	
Employment (log)	0.45	0.814	0.484	0.776	0.796
	(0.850)	(0.833)	(0.848)	(0.830)	(0.835)
Plant vintage	-0.065**	-0.071***	-0.065**	-0.070***	-0.073***
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Public support for NPD	3.443*	4.393**	3.06	3.557*	4.112**
	(1.996)	(1.923)	(1.965)	(1.933)	(1.927)
In-house R&D x PS(-1)	15.620***				
	(2.847)				
In-house R&D x (1-PS(-1))	13.605***				
	(1.887)				
New product sales (-1) x PS(-1)		0.393***			
		(0.063)			
New product sales (-1)x (1-PS(-1))		0.282***			
		(0.044)			
Inn. barrier: Technical skills x PS(-1)			6.106*		
			(3.403)		
Inn. barrier: Technical skills x (1-PS(-1))			-5.972***		
			(2.140)		
Workforce with degree x PS(-1)			-0.007		

			(0.112)		
Workforce with degree x (1-PS(-1))			0.071		
			(0.068)		
Breadth of search x PS(-1)				4.605**	
				(1.986)	
Breadth of search x (1-PS(-1))				2.282*	
				(1.193)	
Breadth of search sqr, x PS(-1)				-0.523	
				(0.328)	
Breadth of search sqr, x (1-PS(-1))				-0.021	
				(0.203)	
Inn. barrier: Lack tech. info x PS(-1)				9.270**	
				(3.769)	
Inn. barrier: Lack tech. info x (1-PS(-1))				-4.258*	
				(2.341)	
Inn. barrier: Regulatory factors x PS(-1)					3.401
					(3.724)
Inn. barrier: Reg. factors x (1-PS(-1))					-3.942*
					(2.153)
Inn. barrier: Lack finance x PS(-1)					3.989
					(3.282)
Inn. barrier: Lack finance x (1-PS(-1))					1.448
					(1.874)
Number of observations	1504	1514	1504	1514	1514
Equation χ^2	444.61	444.203	453.511	458.205	444.664
BIC	8534.391	8598.875	8530.567	8599.58	8601.906

Source: Irish Innovation Panel, waves 2-7 of the survey are included. Observations are weighted to give representative results. Observations are included in the tobit models only where a lagged observation is available to allow estimation of legacy effects. Coefficients reported are marginal effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All models include a set of (10) sectoral and wave dummies (not reported).

Table 4: Estimating additionality effects on new and improved sales from NPD support

	New and improved product sales	New and improved product sales	New and improved product sales	New and improved product sales	New and improved product sales
	(1)	(2)	(3)	(4)	(5)
In-house R&D		25.387***	25.158***	24.759***	24.935***
		(2.465)	(2.456)	(2.446)	(2.458)
New and improved sales (-1)	0.293***		0.288***	0.289***	0.287***
	(0.044)		(0.044)	(0.043)	(0.043)
Innovation barrier: Technical skills	-4.472	-4.467		-4.142	-4.703*
	(2.805)	(2.811)		(2.792)	(2.801)
Workforce with degree	0.061	0.06		0.06	0.058
	(0.089)	(0.089)		(0.088)	(0.088)
Breadth of search	6.340***	6.432***	6.045***		6.207***
	(1.508)	(1.509)	(1.508)		(1.507)
Breadth of search squared	-0.521**	-0.531**	-0.486**		-0.501**
	(0.248)	(0.248)	(0.248)		(0.248)
Innovation barrier: Lack tech. info.	-4.59	-4.55	-3.908		-3.856
	(3.068)	(3.071)	(3.068)		(3.071)
Innovation barrier: Regulatory factors	-0.656	-0.628	-0.64	-0.044	
	(2.741)	(2.743)	(2.734)	(2.728)	
Innovation barrier: Lack finance	1.74	1.644	1.743	1.74	
	(2.400)	(2.401)	(2.393)	(2.383)	
Employment (log)	2.387**	2.406**	2.475**	2.376**	2.370**
	(1.151)	(1.150)	(1.148)	(1.140)	(1.148)
Plant vintage	-0.146***	-0.144***	-0.145***	-0.144***	-0.149***
	(0.037)	(0.037)	(0.037)	(0.037)	(0.037)
Public support for NPD	5.264*	6.035**	5.333**	4.815*	5.196*
	(2.739)	(2.693)	(2.685)	(2.687)	(2.681)
In-house R&D x PS(-1)	29.990***				
	(3.788)				
In-house R&D x (1-PS(-1))	24.420***				
	(2.546)				
New product sales (-1) x PS(-1)		0.330***			
		(0.063)			
New product sales (-1)x (1-PS(-1))		0.290***			
		(0.047)			
Inn. barrier: Technical skills x PS(-1)			7.933*		
			(4.750)		
Inn. barrier: Technical skills x (1-PS(-1))			-7.802***		
			(3.002)		

Workforce with degree x PS(-1)			-0.006		
			(0.154)		
Workforce with degree x (1-PS(-1))			0.084		
			(0.096)		
Breadth of search x PS(-1)				5.938**	
				(2.781)	
Breadth of search x (1-PS(-1))				5.998***	
				(1.671)	
Breadth of search sqr, x PS(-1)				-0.657	
				(0.456)	
Breadth of search sqr, x (1-PS(-1))				-0.412	
				(0.286)	
Inn. barrier: Lack tech. info x PS(-1)				12.968**	
				(5.291)	
Inn. barrier: Lack tech. info x (1-PS(-1))				-8.952***	
				(3.266)	
Inn. barrier: Regulatory factors x PS(-1)					9.823*
					(5.180)
Inn. barrier: Reg. factors x (1-PS(-1))					-3.289
					(2.986)
Inn. barrier: Lack finance x PS(-1)					2.94
					(4.599)
Inn. barrier: Lack finance x (1-PS(-1))					1.482
					(2.594)
Number of observations	1509	1509	1509	1509	1509
Equation χ^2	575.871	574.184	582.626	595.046	581.507
BIC	9350.138	9352.222	9349.667	9349.657	9351.125

Source: Irish Innovation Panel, waves 2-7 of the survey are included. Observations are weighted to give representative results. Observations are included in tobits only where a lagged observation is available to allow estimation of legacy effects. Coefficients reported are marginal effects. * $p <$ 0.1, ** $p < 0.05$, *** $p < 0.01$. All models include a set of (10) sectoral and wave dummies (not reported).

Table 5: Summary of Wald tests for Additionality: By public support for NPD and R&D last period

	Public support for NPD		Public support for R&D	
	New product sales	New and improved product sales	New product sales	New and improved product sales
Input additionality	0.62	2.48	0.72	3.75*
Output additionality	3.08*	0.40	6.87***	4.97**
Behavioural addit.: Congenital	11.82***	10.30***	2.22	2.69
Behavioural addit.: Inter-organ.	17.00***	17.71***	3.28	6.10
Behavioural addit.: Experiential	7.30**	8.83	1.41	3.42

Sources: NPD, models in Tables 2 and 3. R&D models not reported.

Annex 1: Data Definitions

Innovative sales (new) (% sales)	An indicator representing the percentage of firms' sales at the time of the survey accounted for by products which had been newly introduced over the previous three years.
Innovative sales (new and improved) (% sales)	An indicator representing the percentage of firms' sales at the time of the survey accounted for by products which had been newly introduced or improved over the previous three years.
Public support for NPD	A binary indicator taking value one if the firm had received government support for NPD over the previous three years.
Public support for R&D	A binary indicator taking value one if the firm had received government support for R&D over the previous three years.
In plant R&D	A binary indictor taking value one if the firm has an in-house R&D capacity.
Innovation Partnering	An indicator of the number of the breadth of innovation partnering conducted by the firm. Takes values 0 to 10 depending on how many different types of partner firm is working with: group company, supplier, consultant, client, competitor, joint venture, government laboratory, university, private laboratory, industry research centre.
Percentage with degree	Percentage of the workforce with a degree or equivalent qualification.
Innovation barrier: technical skills	A dummy variable indicating whether a firm said technical skills were either a 'major' or 'very major' barrier to innovation.
Innovation barrier: technical information	A dummy variable indicating whether a firm said a lack of technical information was either a 'major' or 'very major' barrier to innovation.
Innovation barrier: regulation or legislation	A dummy variable indicating whether a firm said regulation or legislation was either a 'major' or 'very major' barrier to innovation.
Innovation barrier: finance for innovation	A dummy variable indicating whether a firm said a lack of finance was either a 'major' or 'very major' barrier to innovation.

External search	An indicator of the number of external partner types the firm was working with as part of its innovation activity (takes values 0 to 8).
Exporting firm	A binary indicator taking value one if the firm was selling outside the UK and Ireland.
R&D Department	A binary indictor taking value one if the firm had a formally organised internal R&D department.
Plant vintage	The age of the site (in years) at the time of the survey.
Externally owned	A binary indicator taking value one if the firm was owned outside Ireland at the time of the survey.
Employment	Employment at the time of the survey.

Annex 2: Correlation Matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Sales of new products	(1)	1.000											
Sales of new and improved products	(2)	0.768	1.000										
In-house R&D	(3)	0.278	0.374	1.000									
Workforce with degree	(4)	-0.079	-0.096	-0.132	1.000								
Innovation barrier: Technical skills	(5)	0.133	0.120	0.150	-0.050	1.000							
Breadth of external search	(6)	0.245	0.306	0.309	-0.069	0.133	1.000						
Innovation barrier: Lack technical information	(7)	-0.090	-0.095	-0.100	0.619	-0.022	-0.056	1.000					
Innovation barrier: Regulatory or legislative factors	(8)	-0.109	-0.108	-0.075	0.472	-0.025	-0.063	0.582	1.000				
Innovation barrier: Lack finance for innovation	(9)	-0.014	-0.018	-0.036	0.421	0.013	0.023	0.436	0.393	1.000			
Employment	(10)	0.175	0.161	0.109	-0.072	0.070	0.247	-0.038	-0.064	-0.024	1.000		
Plant vintage (years)	(11)	-0.132	-0.145	-0.048	-0.073	0.000	0.046	-0.016	-0.009	-0.029	0.060	1.000	
Public support: innovation	(12)	0.224	0.255	0.399	-0.053	0.126	0.298	-0.034	-0.094	-0.013	0.097	0.000	1.000

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